XP01002 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

| | | | |
|---|---|---|---|
| Appl'n of: | Kenneth R. Crounse | Art Unit: | 2624 |
| Appl'n no.: | 10/007,440 | Examiner: | Thompson, James A. |
| Filed: | December 4, 2001 | | |
| For: | HALFTONING WITH UNIFORMLY DISPERSED DOT GROWTH | | |

# DECLARATION UNDER 37 C.F.R. §1.131

Commissioner for Patents
P.O. Box 1450
Alexandria, VA. 22313-1450

Dear Sir or Madam:

I, Kenneth R. Crounse, do declare and state:

1. I am the sole inventor of claims 1-44 of the above-identified patent application.

2. I am the author of the attached *draft* 3 page Patent Application: Automatic Generation of Dither Patterns With Uniform Dispersion, Draft 1.0 dated 6/29/01, and the accompanying 3 pages of hand-written notes.

3. Prior to August 27, 2001, I completed the invention as described and claimed in the above-identified patent application as evidenced by:

A. The attached 3 pages of my hand-written notes dated 22 June, 7/11 and 7/13 all in the year 2000 as further evidenced by my insertion on the attached "Agfa Corporation Memorandum of Invention" form. The date of 7/11/00 of the Orig. Notebook Disclosure was hand written by me onto the "Agfa Corporation Memorandum of Invention" form.

B. The "Agfa Corporation Memorandum of Invention" form was signed by me on June 29, 2001.

C. The *draft* 3 page Patent Application: Automatic Generation of Dither Patterns With Uniform Dispersion, Draft 1.0 dated 6/29/01 was authored by me.

D. I reduced to practice my invention by successfully testing proper operation on a computer system prior to 8/27/01 as evidenced by the attached software code document dated 2/13/01, which includes code that has been blackened out to prevent copying.

## DECLARATION UNDER 37 C.F.R. §1.131 (cont)

I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Kenneth R. Crounse 4/24/2006

Kenneth R. Crounse Date

# AGFA CORPORATION
## MEMORANDUM OF INVENTION
Patent Department MS 200-4-LEGAL

| Full Name of Each Inventor | Home Address/Citizenship/Phone Ext. |
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| • 978-658-5600 X5411 | (978) 284-5411 |

| Description of Invention: | Title of Invention: |
|---|---|
| A method for choosing the dither pattern for clustered dot screening. | Automatic Generation of Dither Patterns with Uniform Dispersion |

| (Check all that apply): Invention: | | Documentation: | | Date(s) if known | Reference |
|---|---|---|---|---|---|
| X | Invented in US | X | Orig Notebook Disclosure | 7/11/00 | |
| X | US Inventors | | Orig. Drawings / Sketches | | |
| | Non-US Inventors | X | Software Listings | | |
| | Non-Agfa Inventors | | Foreign Priority Application | | |
| | Joint Agreement | | Built and Tested in US | | |
| X | First Disclosed to: Dale Hubbard | | | | |

**First Commercial Use:**

| | | | | |
|---|---|---|---|---|
| X | **Now in use** Product Name: | internally; output sent to Lexmark, Minolta QMS (testing) | Used since: | Dec 2000 |
| X | **Planned future use** Product Name or type: | ABS Screening toolkit (Lexmark J110 7/01) | FCS date: | 8/01 |

Please attach originals or Photostat copies of any materials checked as documentation for this invention, together with a drawing or block diagram and a brief description of the invention, including: (1) Field to which invention relates; (2) Purpose of the invention; (3) Principle of working, operation, or construction of the invention. Note use drawings with labeled elements.

Signature of Inventor(s):

K. R. Crounse

Witnessed by: Al Ruston This 29-JUN day of JUNE-2001, ~~2000~~

(Witness should, if possible, be those to whom the invention was disclosed)

(For Patent Department Use)

XP Case Number: XP-1002-DitherPattern Opened Date: July 16, 01

# Patent Application: Automatic Generation of Dither Patterns with Uniform Dispersion

*Kenneth R. Crounse*
*Agfa Monotype Corp.*

## Background

A common approach to creating digital halftones is by using a threshold mask to simulate the classical optical approach. This mask is an array of thresholds that spatially correspond to the addressable points on the output medium. At each location an input value is compared to a threshold to make the decision whether to print a dot or not. A small mask (tile) can be used on a large image by applying it periodically.

The first threshold masks were designed to emulate the classical screens. In the simplest case these screens produce halftone dots that are arranged along parallel lines in two directions, i.e. at the vertices of a parallelogram tiling of the plane. If the two directions are orthogonal, the screen can be specified by a single angle and frequency. The halftone dots grow according to a spot function as the desired coverage increases. Many methods have been developed for converting an angle, frequency, and spot function specification to a digital representation, all representing various trade-offs among memory requirements, implementation complexity, and aliasing effects due to the quantization of space

Agfa Balanced Screening allows the use of a square tile to produce screens closely approximating any angle or reasonable frequency. The ABS parameters determine the number of halftone dots contained within a tile and their locations The dot centers do not necessarily lie on the underlying printer grid, but may be "virtual." When the threshold mask is being computed, the halftone dots are created out of real device dot locations which grow around these virtual centers. Furthermore, to allow for more possible levels of coverage, the dot growth is dithered This means that the halftone dots do not grow synchronously; instead each is grown independently in a pre-determined order. Determining this order is the subject of this invention.

## The Problem

The order in which dots grow has a significant effect of apparent screen quality. If the new dots are added in a manner that is not well dispersed, the output may appear mottled or grainy These problems may be especially visible in devices that have very visible device dots or for which there are sudden jumps in the tone reproduction curve. Furthermore, in such devices the interaction between dot growth order in different channels may be important. For example, if the cyan and magenta dot growth locations



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are significantly similar, the dither pattern will be more visible than if they were more dispersed

The Bayer dither is a recursively-defined pattern which is known to have optimal dispersion properties Among other things, the Bayer dither pattern is independent of scale – dots will be placed based only on their relative positions to the other dots. The Bayer dither is most easily applied to a square periodic array of an even power of two number of elements. For these reasons, it cannot be directly applied to the ABS dot center grid (except in the 0 degree case) because the dot centers are oriented at a different angle than the tile shape, and any number of dots are possible. Even in cases where the Bayer dither could be used it is not necessarily desirable in printing systems with visible dots due to the highly regular patterns produced.

Other methods have also been developed for dithering among a small number of dot centers. These methods typically employ a function or set of functions as a measure of dispersion These functions are evaluated at each potential site for the next dither location, as a function of previously chosen nearby dither locations, and the optimal site is chosen These functions are usually embody two strategies: maximizing the distance from adjacent dots in the pattern and minimizing the variance among those distances. Such strategies are best used with a small number of dot centers because they are inherently local – if many potential sites were to have similar neighborhoods the method could only choose among them at random This can lead to unpleasant white-noise structure at various levels in the dither pattern

## Summary of the Invention

Our invention creates a dither pattern for a large number of dot centers with the both global and local (scale-invariant) properties of the Bayer dither, but with the less-obvious structures that can be produced by other methods. The method is based on the minimization of a convolution-style "cost" functional $H_j = \sum_k f(d_{j,k})$. That is, each potential next dot center in the dither order is evaluated in terms of a sum of a specific function $f$ of the distances between the candidate dot center and all other previously chosen dot centers. The dot with the minimum "cost" is chosen, and the process is iterated.

There are an infinite number of possible functions of distance that could be considered, but the properties of this function are critical. For example, it seems reasonable to find a dot center that is furthest away from all others by minimizing the negative sum of square distances. However, attempting to apply this cost function can lead to the situation where dots are placed very close to each other in two separate clumps In fact, it can be shown that the cost function must be sufficiently concave as a function of distance (the sum of distances is not), which ensures that local decisions take priority over global ones. Another feature the function should contain is invariance to arbitrary dilations or contractions of scale. That is, if the units of measurement are arbitrarily scaled, the costs



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will maintain their relationships. This straightforward requirement is essential for scale-invariance but is not found in such promising functions as the gaussian or exponential decay functions

The class of functions that we have chosen for this purpose is the power laws:

$f \equiv \frac{1}{d^{\alpha}}$ where $\alpha > 1$,

which can be shown to have the desired properties. In fact, when using this function and starting with any single initial dot center, the algorithm will produce an ideal Bayer dither pattern (up to certain symmetries) on any tile where it is possible In other cases, the Bayer pattern is produced up to the point where the sub-grids contain no further factors of two. To produce patterns with less structure the algorithm must be initialized with two or more chosen dot centers which are not symmetric. Then, the pattern produced will still maintain both local and global dispersion but will not follow the standard Bayer dither order.

When designing dot dither order for two screens simultaneously, a similar technique can be used The next dot in the order is chosen for each screen alternately First the cost function described above is used to assess the possible locations. Then, a (possibly different) measure of the dispersion to the chosen centers in the other screen is also evaluated These two results are combined to produce a best choice. There are many possible choices of the cross-screen dispersion measure and the method of combining the two cost functions. The cross-screen dispersion measure does not need to have global properties, since this is preferably handled by the self-dispersion measure For this reason we use the negative maximal minimum distance as the cross-screen dispersion measure. These measures are combined by first selecting the N best choices according to the self-dispersion measure, and then selecting of those the one with the best cross-screen dispersion. As the number of selected dots increases and the choices become more constrained, N can be decreased so that self-dispersion is given more priority

# From Notebook

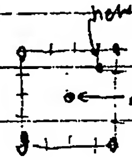
~~Matlab ...~~

2/25/ure Dither order.

Fixed ABS so that it does actually use the sum of square distances to choose among equivalent cases.

As expected, the results are horrible – it prefers to put a dot close to an existing dot because of the large square sums to the other 3 dots

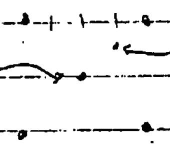
new dot: 40



not here.
=32

try old method but use all dots ... period ...

What if we use square roots, ie $dist = \sum_i \sqrt{(x_i - x)^2 + (y_i - y)^2}$



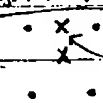
$2\sqrt{10} + 3\sqrt{2} + \sqrt{2} = 11.98$

$11.31 = 8\sqrt{2}$

hah!

6/23

~~doesn't work!~~



So what will work? Ideas-

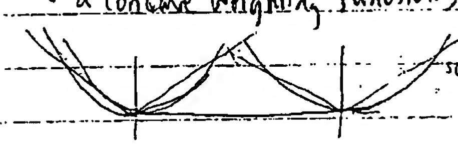
- geometric mean, ie $\prod \sqrt{(x_i - x)^2 + (y_i - y)^2}$ and maximize it. use log

$(2\sqrt{2})^4 = 2^4 2^2 = 2^6 = 64$

$\sqrt{10}\sqrt{10}\,3\sqrt{2}\sqrt{2} = 60$

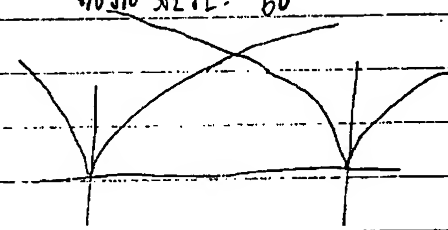
wrap-around effect seems critical

- a concave weighting function, maximize



linear distance

square dist



$\sqrt{r}$

doesn't work

- a convolution-type weighting function, minimize

same as minimizing a well-behaved convolution (?) ie $e^{-r}$-like

interpretation – measures how much other dots are influencing that space, or how much the new dot will "interact" with the others

use a HVS-based weighting function

- try to minimize smoothed variance, ie $g(x,y) = h(x,y) + \sum_i h(x - x_i, y - y_i)$

the function h could be a HVS model $\min_{x,y} \int (g(x,y) - \bar{g}(x,y))^2$

in general may want to introduce a angle dependence to reduce HVS effect.

- minimize the variance of the distances.

cont'd from 6/22

7/11 Dot Dither Order

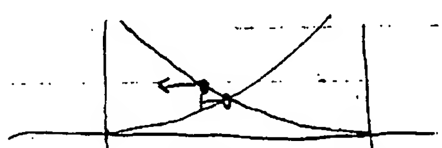
Observations - since the pattern is periodic, any "energy" function is also periodic; need only consider one period centered at the cell under consideration. * This is equivalent to Paul's method of finding the "closest" periodic replication of a given dot.

Since only one period is considered, maximizing a functional can be recast as a minimization

$$\max \sum_k f(r_k) \equiv \min \sum_k -f(r_k) + C \qquad \text{where } C = \max_{r \in \text{period}} f(r)$$

but numerically one or the other may be preferable

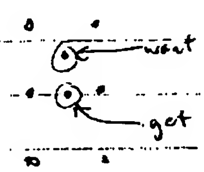
when maximizing, a concave function like $r^2$ is not appropriate, since it favors endpoints, not midpoints


always an advantage to move away from midpoint

tried $\sqrt{r}$

$1-e^{-r}$

both fail on some important cases, in particular


want

get

trying $\frac{1}{r^2}$ which does seem to work on the case of interest *for all scales*

since $\frac{1}{(kr)^2} = \frac{1}{k^2} \frac{1}{r^2}$

ideally would like an analytical decision or use HVS.

→ seems to work very well, producing Bayer patterns. Would be nice to break the crystalline symmetry — did this by fixing a dot at $nd/3$

$\frac{1}{r^{1.5}}$ gives better "long-range" decisions

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7/13 Dot Order Dither

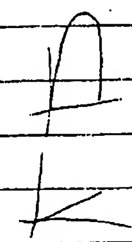
The $\frac{1}{r^{1.5}}$ function worked very well – produced a D_32_32.ORD as needed by Doug Obrecht (Minolta QMS). Printouts confirm good performance.

Directions to take Order file generation

1) speed. the algorithm is very inefficiently implemented.

currently order $\sum_{k=0}^{N} k(N-k)B$

can be reduced to $\sum_{k=1}^{N} kB$ by storing intermediate sums



2) breaking symmetry. right now I'm choosing cell 0 and cell $nd/3$ to start which give some symmetry breaking. For small tile sizes, it leads to some bothersome phase boundaries.

Idea to try:

Select among cells which are close to the minimum energy by some percentage, then choose (randomly) among them.

3) adjustable energy spread function, $\frac{1}{r^a}$ $a>1$

4) adjustable anisotropy, to match HVS or compensate for printer behavior.

For HVS, want more spread in the diagonal (?)

Seems like $\ell_1$ would be right, but maybe $\ell_\infty$

7

8



```
/*********************************************************************
*********
* FILE: abs_cdo.c
[redacted]
* modified by Ken Crounse 2001-02-13
* ABSTRACT: module to calculate an optimized order to make the
halftone dots
* grow
**********************************************************************
*********/

#ifndef _abs_cdo_
#include "abs_cdo.h"
#endif _abs_cdo_

char abs_cdo_mod[80];
char abs_cdo_mess[80];

/*********************************************************************
*********
* Calculate the square of a double number
**********************************************************************
*********/
double abs_cdo_square(
  double x)
{
return(x*x);
}

/*********************************************************************
*********
* Normalize a double number as follows:
* first divide the argument "x" by "s" (the scale)
* If the resulting number is positive, return the decimal fraction
* If it is negative, use the complement of the fraction
**********************************************************************
*********/
[redacted]
/*********************************************************************
*********
* Calculate the normalized distance between two points (x1,y1) and
(x2,y2)
* that located in a tile with a horizontal tilesize (xs) and vertical
* tilesize (ys).
* The distance calculation takes into account the "wrap around"
properties
* of the tile in both the horizontal and vertical directions and
returns the
* "shortest" distance from (x1,y1) to (x2,y2) in any of the 9 possible
* directions.
**********************************************************************
*********/
[redacted]
{
[redacted]
    {
[redacted]
    }
  }
[redacted]
}

/*********************************************************************
*********
* Calculation of the sequence that is used to make the halftone dots
grow.
* The algorithm works as follows:
* Suppose that there are nd dots in a tile, divided into a first group
of n1
* dots that have already received a ranking number (they can be
recognized
* by having a "mark" set to one) and a second group of n2 dots that
have not
* received yet a ranking number.
*
* The question is than which of the n2 dots will receive the next
ranking
* order.
*
```

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